Respectfully submitted,

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Appendix A

CDMA and How it Promotes Spectrum Efficiency

I. Why CDMA Should be Used as the Modulation Choice for low-earth orbit MSS/RDSS Systems

CDMA is the appropriate technology for high capacity and multiple system provider services. CDMA has been shown to allow multiple system providers to more effectively share frequencies by multiple system bandwidth sharing within a service area. CDMA systems retain a significant portion of the non-sharing capacity even when faced with a single similar competing system. Finally, CDMA's low power spectral density reduces interference into other non-MSS systems which share the bands.

CDMA is the most spectrum efficient sharing method because:

(1) the way to efficient use of the spectrum is through spectrum reuse;

(2) all efficient spectrum reuse schemes end up being interference limited;

(3) when the system is interference limited, CDMA is the best multiple access technique.

CDMA is the appropriate technology for high capacity and multiple system provider services. CDMA has been shown to allow multiple system providers to more effectively share frequencies by multiple system bandwidth sharing within a service area. CDMA systems retain a significant portion of the non-sharing capacity even when faced with a single similar competing system. This means that the aggregate capacity of two systems is greater than 100 percent of the capacity of one system.

TDMA or FDMA, on the other hand, is inherently incapable of producing any capacity gain from the operation of more than one system. This occurs because the TDMA approach is fundamentally bandwidth limited. There are only so many channels and slots available in a given service area. Providing another satellite with co-coverage can only be useful if there is more capacity provided by the presence of an additional system. In fact, less capacity results when there are multiple systems using TDMA. Moreover, with competing TDMA systems (with equal division of available channels) has additional waste, since there is no way for a more heavily loaded system to gain additional channels while the lightly loaded system wastes its allocation. This is not the case with CDMA sharing.

The best approach with CDMA is to overlay the CDMA systems in the same frequency band with no fixed or predetermined divisions of channel resources.

Each operator can load its system until the system runs out of link margin. This means that the operator that provides the best service or lower rates or whatever consumers prefer will be able to use more than an allocated portion of the available spectrum. In short, systems utilizing CDMA maximize the use of the spectrum and efficiently adjust on a dynamic basis to serve the public. Further more, there is no need to synchronize the systems.

In a well designed, wide area communications system employing CDMA spectrum reuse, most of the interference comes from other homogeneous system users. With CDMA, capacity sharing boils down to power sharing, and therefore, interference from non-homogeneous CDMA sources consumes a small portion of the system's capacity. If the non-homogeneous interference sources are as efficient in their own use of power as the CDMA system, then a fair division of capacity resources can be made. If other systems are homogeneous, the utilization of spectrum resources is even more efficient. By being homogeneous, all systems would be designed to the same principles (direct sequence CDMA, power control, etc.) and no user/system would use more power than required. Thus, for maximum utilization of the scarce resources of the MSS bands, homogeneous CDMA systems should be adopted. Systems using TDMA or FDMA should be rejected.

Interference to other band users such as GLONASS from a CDMA system also will be minimized on a per-user basis for several reasons:

(1) power control, inherent in CDMA minimizes need for margins in the system link budget, thereby the system only applies margin on a link by link basis and only when required;

(2) because the spectrum already is being spread means that low rate convolutional codes can be used to lower the Eb/No and therefore the transmitted power;

(3) voice activity gating reduces interference from transmitters when voice users are not talking;

(4) CDMA allows universal frequency reuse so that all beams can use all frequencies rather than being forced into some type of plan (i.e., 1/7) such as TDMA;

(5) wide-band signal spectrum produces a noise-like interference characteristic in other systems, unlike TDMA which produces pulse-like interference;

(6) when a CDMA is operating at less than full capacity, interference to other systems will be reduced proportionally. This is in contrast with TDMA systems which continue to produce full power transmit bursts even when only

one user is talking.

A properly designed CDMA system is the most benign in its interference to other types of systems that may be sharing the same spectrum while still providing the most efficient use of the spectrum when fully operating.

II. Characteristics of CDMA that enable efficient use of spectrum

The following pages are excerpts from a document prepared by QUALCOMM, Inc., to assist the TIA TR45 Committee in its development of digital cellular standards. These selected pages provide background information about CDMA technology, how it utilizes spectrum, its operational characteristics and ability to accommodate multiple users within the same spectrum. Although this material was developed for use in the terrestrial cellular forum, it is equally applicable to the use of CDMA within the Globalstar system.

2.0 THE CDMA CONCEPT

CDMA is a modulation and multiple access scheme based on spread spectrum communication, a well-established technology that has been applied only recently to digital cellular radio communications and advanced wireless technologies. The approach will solve the near-term capacity concerns of major markets and the industry's long-term need for an economic, efficient, and truly portable communications.

Ever since the second pair of wireless telegraphs came into existence, we have been confronted with the problem of multiple access to the frequency spectrum without mutual interference. In the early days of wireless telegraphy, both frequency division in the form of resonant antennas, time division in the form of schedules, and netted operations were employed. As the number of wireless radios in operation increased and as the technology allowed, it became necessary to impose some discipline on the process in the form of frequency allocations. This has grown over the years to the complex process we have today for world-wide frequency allocations and licensing by service type.

The multiple access problem can be thought of as a filtering problem. There are as many simultaneous users that want to use the same electromagnetic spectrum and there is a choice of an array of filtering and processing techniques which allow the different signals to be separately received and demodulated without excessive mutual interference. The techniques that have long been used include: propagation mode selection, spatial filtering with directive antennas, frequency filtering, and time sharing. Over the last 40 years, techniques involving spread spectrum modulation have evolved in which more complex waveforms and filtering processes are employed.

Propagation mode selection involves a proper choice of operating frequency and antenna so that signals propagate between the intended communicators but not between (very many) other communicators. Frequency reuse in cellular mobile telephone systems is an example of this technique carried to a great degree of sophistication.

Spatial filtering uses the properties of directive antenna arrays to maximize response in the direction of desired signals and to minimize response in the direction of interfering signals. The current analog cellular system uses sectorization to a good advantage to reduce interference from co-channel users in nearby cells.

With FDMA, a channel is a relatively narrow band in the frequency domain into which a signal's transmission power is concentrated. Different signals are assigned different frequency channels. Interference to and from adjacent channels is limited by the use of bandpass filters which pass signal energy within the specified narrow frequency band while reject signals at other frequencies. The analog FM cellular system uses FDMA.

FDMA spectral efficiency in a cellular system is determined by the modulation spectral efficiency (the information bit rate per Hertz of bandwidth) and the frequency reuse factor. The U.S. analog cellular system, divides the allocated spectrum into 30 kHz bandwidth channels; narrowband FM modulation is employed, resulting in a modulation efficiency of 1 call per 30 kHz of spectrum. Because of interference, the same frequency cannot be used in every cell. The frequency reuse factor is a number representing how often the same frequency can be reused. To provide acceptable call quality, a Carrier-to-Interference ratio

(C/I) of 18 dB or greater is needed. Empirical results have shown that in most cases this level of C/I requires a reuse factor of seven. The resulting capacity is one call per 210 kHz of spectrum in each cell. Note that by increasing the number of cells, an arbitrarily high capacity can be obtained, but with increased equipment costs. In addition, there also is a cost of increasing handoff rates as mobile stations move through smaller coverage areas.

With TDMA, a channel consists of a time slot in a periodic train of time intervals making up a frame. A given signal's energy is confined to one of these time slots. Adjacent channel interference is limited by the use of a time gate that only passes signal energy which is received at the proper time. Some systems use a combination of FDMA and TDMA. The TIA proposed EIA/TIA/IS-54-B digital cellular standard uses 30 kHz FDMA channels which are subdivided into six time slots for TDMA transmissions. Two time slots are required for each call when employing 8 kbps vocoders.

TDMA spectral efficiency is determined in a manner similar to that used for FDMA. The EIA/TIA/IS-54-B TDMA standard provides a basic modulation efficiency of three voice calls per 30 kHz of bandwidth. The currently accepted frequency reuse criteria is similar to the analog design. The resulting capacity is one call per 70 kHz of spectrum or three times that of the analog FM system.

With CDMA, (see Figure 2-1) each signal consists of a different pseudorandom binary sequence that modulates the carrier, spreading the spectrum of the waveform. A large number of CDMA signals share the same frequency spectrum. If CDMA is viewed in either the frequency or time domain, the multiple access signals appear to be on top of each other. The signals are separated in the receivers by using a correlator which accepts only signal energy from the selected binary sequence and despreads its spectrum. The other users' signals, whose codes do not match, are not despread in bandwidth and as a result, contribute only to the noise and represent a self-interference generated by the system.

The increased signal-to-noise ratio for the desired signal is shown in Figure 2-2. The signal-to-interference ratio is determined by the ratio of desired signal power to the sum of the power of all the other signals, and is enhanced by the system processing gain or the ratio of spread bandwidth to baseband data rate. As discussed in Section 3, the major parameters that determine the CDMA digital cellular system capacity are processing gain, required E_b/N_0, voice duty cycle, frequency reuse efficiency, and the number of sectors in the cell.[1] The CDMA cellular telephone system achieves a spectral efficiency of up to 20 times the analog FM system efficiency when serving the same area with the same antenna system. This is a capacity of up to one call per 10 kHz of spectrum.

In the cellular radio frequency reuse concept, interference is accepted but controlled with the goal of increasing system capacity. CDMA does this effectively because it is inherently an excellent anti-interference waveform. Since all calls use the same frequencies, CDMA

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[1] E_b/N_0 is defined as the bit energy to noise power spectral density: comparable to C/I.

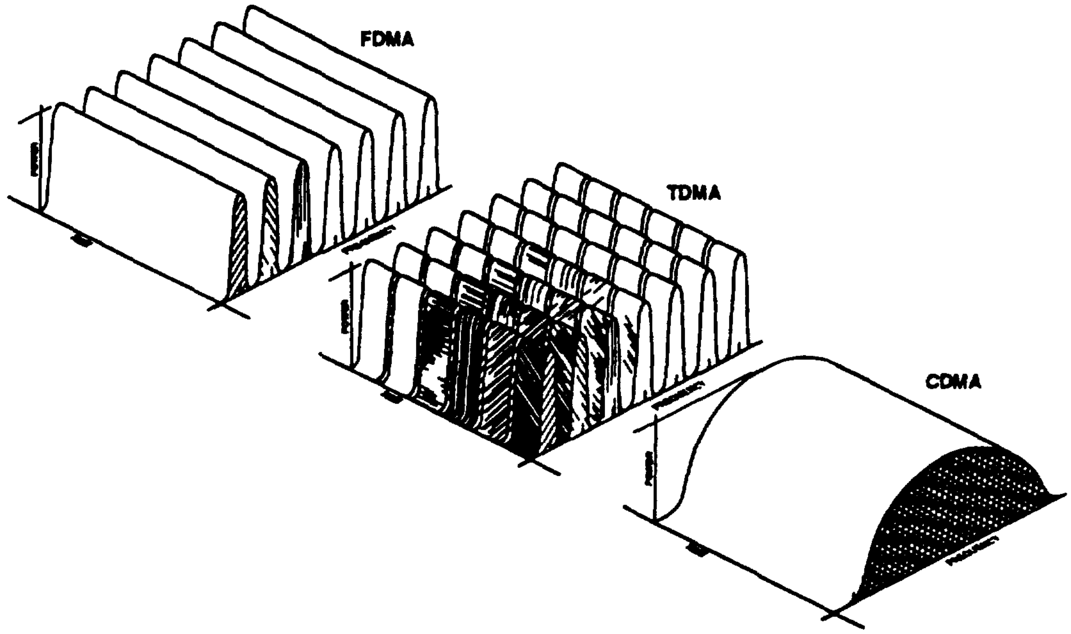

Figure 2-1. ***Frequency and Time Domain Representations of FDMA, TDMA, and CDMA.*** *Unlike FDMA or TDMA, CDMA has multiple users simultaneously sharing the same wide band channel. Individual users are selected by correlation processing of the pseudonoise waveform.*

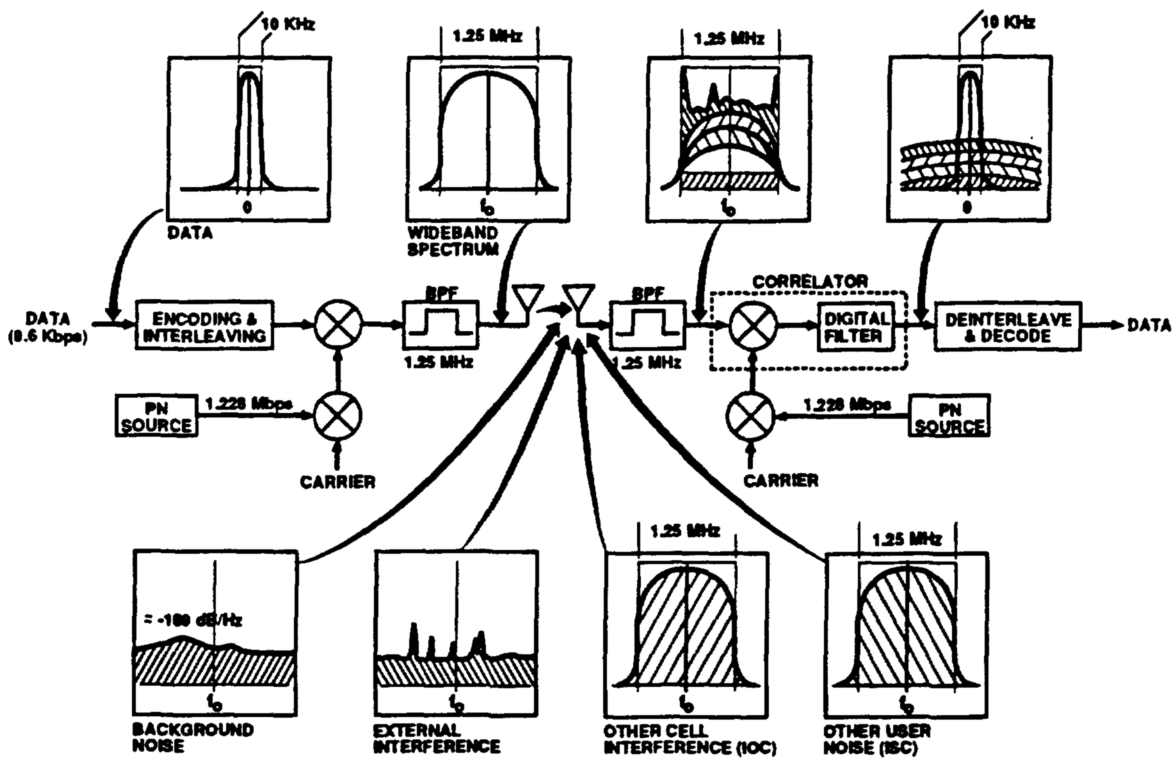

Figure 2-2. ***A View of the CDMA Concept.*** *The desired signal is selected from four different sources of interference. The dominant source is system self-interference produced by other users of the same cell. This source is controlled by closed loop power control.*

frequency reuse efficiency is determined by a small reduction in the signal-to-noise ratio caused by system users in neighboring cells. CDMA frequency reuse efficiency is approximately 2/3 compared to 1/7 for narrowband FDMA systems. The CDMA system can also be a hybrid of FDMA and CDMA techniques where the total system bandwidth is divided into a set of wideband channels, each of which contains a large number of CDMA signals.

2.1 CDMA System Overview

The multiple access scheme exploits isolation provided by the antenna system, geometric spacing, power gating of transmissions by voice activity, power control, and very efficient modem and a signal design which uses error correction coding.

A combination of open loop and closed loop power control (through measurements of the received power at the mobile station and the base station) commands the mobile station to make power adjustments in order to maintain only the power level required for adequate performance. This minimizes interference to other users, helps to overcome fading, and conserves battery power in the mobile station.

The CDMA digital cellular waveform design uses a Pseudorandom Noise (PN) spread spectrum carrier. The chip rate of the PN spreading sequence was chosen so that the resulting bandwidth is about 1.25 MHz after filtering or approximately one-tenth of the total bandwidth allocated to one cellular service carrier.

The Federal Communications Commission (FCC) has allocated a total of 25 MHz for mobile station to cell site and 25 MHz for cell site to mobile station for the provision of cellular services. The FCC has divided this allocation equally between two service providers, the A and the B carriers, in each service area. The channel number denotes the FM (30 kHz) channels. Because the FCC increased the cellular frequency allocations, the 12.5 MHz allocated to each carrier for each direction of the link is further subdivided into two subbands. For the B carriers, the subbands are 10 MHz and 2.5 MHz each. For the A carriers, the subbands are 11 MHz and 1.5 MHz each. A signal bandwidth of less than 1.5 MHz fits into any of the subbands, while a bandwidth of less than 2.5 MHz fits into all but one subband.

A set of ten 1.25 MHz bandwidth CDMA channels can be used by each operator if the entire allocation is converted to CDMA. Initially, only one or a small number of 1.25 MHz channels need to be removed from the present FM analog service to provide digital service. This facilitates the deployment by introducing a more gradual reduction in analog capacity. Each 1.25 MHz CDMA segment can provide about twice the capacity of the entire 12.5 MHz allocation using the present FM system. Some frequency guard band is necessary if there are adjacent high power cellular (or other) frequencies in use and the maximum capacity of the CDMA cell is required. Capacity can be sacrificed for decreased guard band if desired. Adjacent CDMA channels need not employ a guard band.

3.0 CDMA SYSTEM BENEFITS

This section highlights some of the major attributes of the digital cellular system developed by QUALCOMM and briefly describes the features, summarized in Table 3-1, that provide these benefits. While the CDMA system employs dual-mode subscriber units to provide compatibility with the analog system, only the features peculiar to CDMA are discussed here. More detailed descriptions of the system and its functionality are contained in Section 4.

3.1 Multiple Forms of Diversity

In relatively narrowband modulation systems such as analog FM modulation employed by the first generation cellular phone system, the existence of multiple paths causes severe fading. With wideband CDMA modulations, however, the different paths may be independently received greatly reducing the severity of the multipath fading. Multipath fading is not completely eliminated because multipaths which cannot be independently processed by the demodulator occasionally occur. This will result in some fading behavior.

Diversity is the favored approach to mitigate fading. There are three major types of diversity: time, frequency, and space. Time diversity can best be obtained by the use of interleaving and error correction coding. Wideband CDMA offers a form of frequency diversity by spreading the signal energy over a wide bandwidth; frequency selective fading usually affects only a 200-300 kHz portion of the signal bandwidth. Space or path diversity is obtained three different ways by providing the following:

- Multiple signal paths through simultaneous links from the mobile station to two or more cell sites (soft handoff).
- Exploitation of the multipath environment through spread spectrum processing (rake receiver), allowing signals arriving with different propagation delays to be received separately and combined.
- Multiple antennas at the cell site.

The different types of diversity employed in the CDMA system to greatly improve performance are shown in Figure 3-1 and summarized below:

- Time Diversity - symbol interleaving, error detection, and correction coding
- Frequency Diversity - 1.25 MHz wideband signal
- Space (Path) Diversity - dual cell site receive antennas, multipath rake receivers, and multiple cell sites (soft handoff)

Antenna diversity can easily be provided in FDMA and TDMA systems. Time diversity can be provided in all digital systems that can tolerate the required higher transmitted symbol rate needed to make the required error correction process effective. However, the other methods can only be provided easily with CDMA. A unique feature of direct sequence CDMA is the ability to provide extensive path diversity; the greater the order of diversity in a system, the better the performance in this difficult propagation environment.

Multipath processing takes the form of parallel correlators for the PN waveform. The mobile and cell receivers employ three and four parallel correlators respectively. Receivers using parallel correlators (sometimes called rake receivers) allow individual path arrivals to be tracked independently and the sum of their received signal strengths is then used to demodulate the signal. While there is fading on each arrival, the fades are independent. Demodulation based on the sum of the signals is then, much more reliable.

The multiplicity of correlators is also the basis for the simultaneous tracking of signals from two different cells and allows the subscriber unit to control the soft handoff described in 3.6.

3.2 Power Control in CDMA

To achieve high capacity, quality, and other benefits, the CDMA mobile telephone system employs forward (cell-to-mobile) and reverse link (mobile-to-cell) power control. The objective of the mobile station transmitter power control process is to produce a nominal received signal power from each mobile station transmitter operating within the cell at the cell site receiver. Regardless of a mobile station's position or propagation loss, each mobile station's signal will be received at the cell at the same level. If all the mobile station transmitters within a cell site's area of coverage are so controlled, then the total signal power received at the cell site from all mobile stations is equal to the nominal received power times the number of mobile stations.

Each CDMA receiver at the cell site operates by converting a selected CDMA signal from one of the mobile station transmitters into a signal that carries narrowband digital information. At the same time, the other signals that are not selected remain wide bandwidth noise signals (see Figure 3-1). The bandwidth reduction processing, commonly called processing gain, increases the signal-to-interference ratio (in dB) from a negative value to a level that allows operation with an acceptable bit error rate.

It is very desirable to maximize the capacity of the CDMA system in terms of the number of simultaneous telephone calls that can be handled in a given system bandwidth. The system capacity is maximized if the transmit power of each mobile station is controlled so that its signal arrives at the cell site with the minimum required signal-to-interference ratio.

If a mobile station's signal arrives at the cell site with too low a value of received power, the bit error rate is too high to permit high quality communications. If the received power is too high, the performance of this mobile station is acceptable, but interference to all the other mobile station transmitters that are sharing the channel is increased, and may result in unacceptable performance to other users unless the capacity is reduced.

Reverse link open loop power control, reverse link closed loop power control, and forward link power control are employed in the CDMA system as shown in Figure 3-2. Reverse link open loop power control is primarily a function of the mobile stations. The goal of the open loop portion of reverse link power control is for the mobile station to rapidly adjust transmit power according to changes in received power from the cell. The mobile stations measure the received power level from the cell sites and adjust their transmitter power in an in

Table 3-1. CDMA Features Supporting CTIA's User Performance Requirements

Feature - Description
High Capacity. Field tests in diverse environments have verified the predictions for CDMA in that capacities averaging 15 times greater than analog were achieved under stressed conditions. In terms of Erlangs offered at any grade of service, the advantage is even greater. Finally, if the existing half rate vocoder is used, the capacity increases by a factor of 1.7. Additional sectorization (beyond 3) also increases capacity.
High Quality Service. A variable rate vocoder provides digital voice and highly rated voice reproduction. Background levels are muted even under heavy load. The system independently tracks individual multipath arrivals to greatly reduce the susceptibility to fading. The CDMA soft handoff technique provides a totally transparent handoff of calls. This robust handoff technique virtually eliminates dropped calls and reduces switching loads.
System Evolution. Digital data traffic and paging services are included in the current system. FAX protocols are supported by the existing control structure. Higher data rates can be provided (9.6 kbps is the current level). CDMA-only portables that are compatible with both cellular and PBX operations can meet localized needs.
Ability to Introduce New Features. If desired, a common instrument can access private wireless PBXs, residential cordless, public digital cordless, PCN, and cellular systems; simple interface to ISDN, PBX and PSTN is provided. The digital control signaling provided allows a variety of data services that can be added as the carrier expands the scope of services offered. The variable rate vocoder and data service allow multiple grades of service. Range measurements inherent with the waveform will allow mobile position determination.
Privacy. The digital format, wideband signaling, and addressee-specific traffic protection features provide an unmatched combination of privacy features.
Ease of Transition (and Compatibility with Analog). The initial service using a single CDMA channel and the transfer of the high usage customers to CDMA nearly triples current capacity and provides better service quality for both CDMA and analog users. Capacity and coverage characteristics allow CDMA introduction with far fewer cells than used in current networks. Antenna coverage and sectorization are independent from cell to cell, and not closely dependent as in narrowband systems. Subsequent growth is incremental and can be localized (to provide hot spot coverage) or global. CDMA subscriber units are dual-mode so they can access either CDMA or analog channels.
Availability and Cost. Current estimates of CDMA system costs in terms of network equipment as well as subscriber equipment show them to be equivalent to current analog costs. Capacity improvement allows service with far fewer cell sites than analog/TDMA, reducing installation and operating costs. Proven ASIC technology has reduced the sophisticated signaling technology to very simple manufacturing technology. Mobile subscriber equipment will be available in the third quarter of 92; handheld portables in the first quarter of 93; and infra-structure equipment in the second quarter of 93.
Cellular Open Network Architecture (CONA). Base Station/MTSO interfaces are being addressed that would allow independent development of switch and Base Station equipment.

indirectly proportional manner. Open loop power control attempts to have all mobile station transmitted signals arrive at the cell site with the same nominal power level. The cell site supports the open loop control function by providing a calibration constant to the served mobile stations. The calibration constant is determined primarily by the cell site ERP. Cells that transmit at a higher than nominal ERP must inform their subscribers so the mobile stations will not transmit lower than nominal required power and conversely for low ERP cell sites.

The cell site takes an active role in the reverse link closed loop power control functions. The goal of the closed loop portion is for the cell to provide rapid corrections to the mobile station's open loop estimate to maintain the optimum transmit power. The cell measures the relative received power level of each of the associated mobile station's signals and compares it to an adjustable threshold. A determination is made every 1.25 ms to either transmit a power-up command or a power-down command to the mobile station. This closed loop correction to any variation required in the open loop estimate accommodates gain tolerances and unequal propagation losses between the forward and reverse links.

The cell supports forward link power control by adjusting the forward link power for each subscriber link signal in response to measurements provided by the mobile station. The purpose is to reduce power for units that are either stationary, relatively close to the cell site, impacted little by multipath fading and shadowing effects, or experiencing minimal other cell interference. Thus, extra power can be given to units that are either in a more difficult environment or far away from the cell and experiencing high error rates.

3.3 Low Transmit Power

Besides directly improving capacity, one of the more important results of reducing the required E_b/N_0 (signal-to-interference level) is the reduction of transmitter power required to overcome noise and interference. This reduction means that mobile stations also have reduced transmitter output requirements which reduces cost and allows lower power units to operate at larger ranges than the similarly powered analog or TDMA units. Furthermore, a reduced transmitter output requirement increases coverage and penetration and may also allow a reduction in cells required for coverage.

An even greater gain is the reduction of average (rather than peak) transmitted power that is realized because of the power control used in CDMA. Most of the time propagation conditions are benign. Narrow band systems must always transmit with enough power to override the occasional fades. CDMA uses power control to provide only the power required at the time, and thus reduces the average power by transmitting at high levels only during fades.

3.4 Vocoder and Variable Data Rates

The vocoder (voice encoder/decoder) in the CDMA system is an 8 kbps variable rate design. The variable data rate two-way voice service option, Service Option 1, provides two-way voice communications between the base station and the mobile station by using a dynamically variable data rate vocoder algorithm. The transmitting vocoder takes voice samples and generates an encoded speech packet for transmission to the receiving vocoder.

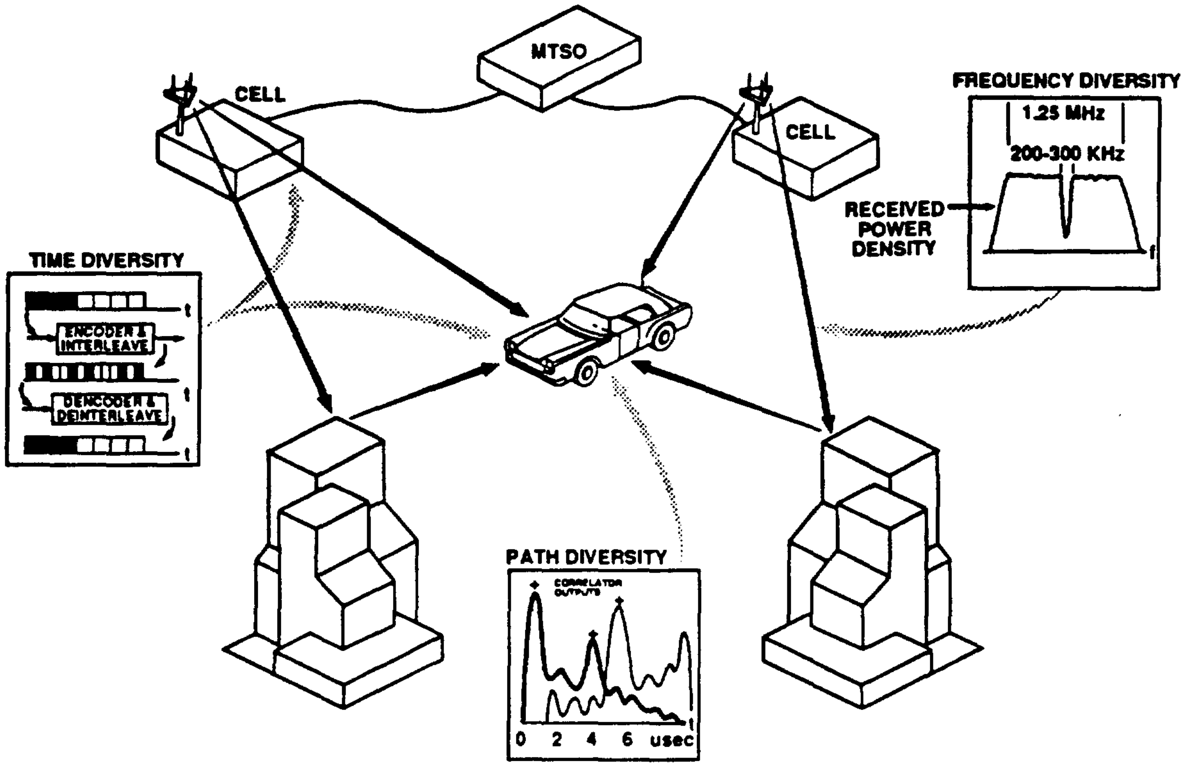

***Figure 3-1.* Diversity Processes in CDMA.** *The reception from two different cells, wide band, signal structure, along with the capabilities of the rake receiver allow CDMA three forms of diversity in addition to the time diversity available in other digital systems.*

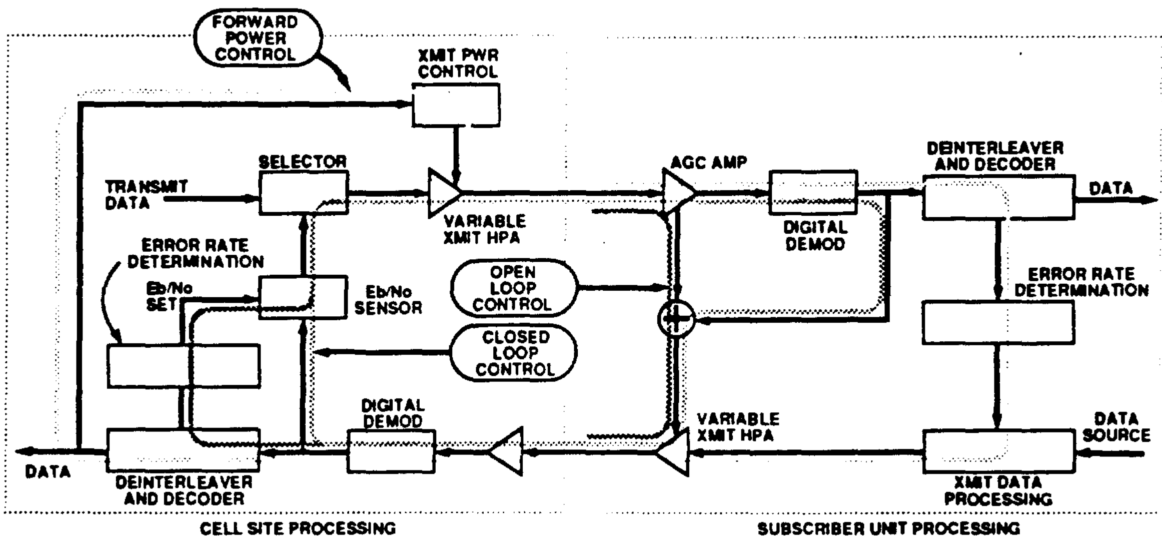

***Figure 3-2.* Power Control in CDMA.** *Fast open loop and closed loop control maintains the reverse link transmit power at a selectable level. A slower loop limits the forward link to only that power required.*

then the receiving vocoder decodes the received speech packet into voice samples. The two vocoders communicate at one of four rates corresponding to the 9600 bps, 4800 bps, 2400 bps, and 1200 bps frame rates. The rates are determined by the input, messaging, or data. The vocoder algorithm uses Code Excited Linear Prediction (CELP) and the CDMA-specific algorithm is termed QCELP.

An important feature of the variable rate vocoder is the use of adaptive thresholds to determine the required data rate. The thresholds are changed according to the background noise level activating the higher vocoder rates only on the local voice. The result is suppression of the background and good voice transmission even in a noisy environment.

3.5 Privacy

The scrambled form of CDMA signals provides for a very high degree of privacy and makes this digital cellular system inherently more immune to cross-talk, inexpensive scanning receivers, and air-time fraud. The proposed standard includes the authentication and voice privacy features specified in EIA/TIA/IS-54-B even though the CDMA architecture inherently provides voice privacy and provisions for extended protection. The digital voice channel is, of course, amenable to direct encryption using DES or other standard encryption techniques.

3.6 Mobile Station Assisted Soft Handoff

As shown in Figure 3-3, soft handoff allows both the original cell and a new cell to temporarily serve the call during the handoff transition. The transition is from the original cell to both cells and then to the new cell. Not only does this greatly minimize the probability of a dropped call, but it also makes the handoff virtually undetectable by the user. In this regard, the analog system (and the digital TDMA-based systems) provides a break-before-make switching function whereas the CDMA-based soft handoff system provides a make-before-break switching function.

After a call is initiated, the mobile station continues to scan the neighboring cells to determine if the signal from another cell becomes comparable to that of the original cell. When this happens, it indicates to the mobile station that the call has entered a new cell's coverage area and that a handoff can be initiated. The mobile station transmits a control message to the MTSO which states that the new cell site is now strong and identifies the new cell site. The MTSO initiates the handoff by establishing a link to the mobile station through the new cell while maintaining the old link. While the mobile station is located in the transition region between the two cell sites, the call is supported by communication through both cells; thereby eliminating the ping-ponging effect, or repeated requests to hand the call back and forth between two cell sites. The original cell site will only discontinue handling the call when the mobile station is firmly established in the new cell.

3.7 Capacity

In the cellular frequency reuse concept, interference is accepted but controlled with the goal of increasing system capacity. CDMA does this effectively because it is inherently a better anti-interference waveform than FDMA or TDMA. Indeed, its genesis was in military anti-jamming systems. Narrowband modulations are limited in frequency reuse efficiency by the

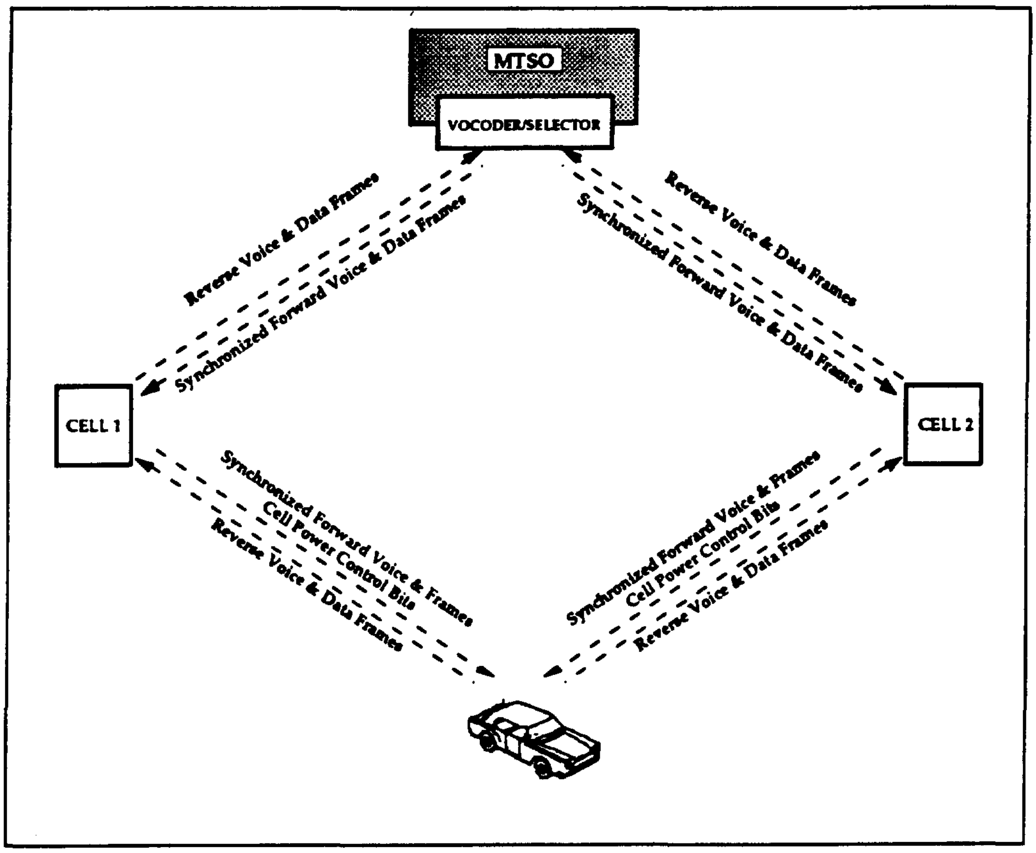

Figure 3-3. ***Active Links During Handoff.*** *Following notification by the subscriber which identifies the desired new cell, the MTSO activates the new cell and communication is supported through both cells until the subscriber notifies the MTSO that one of the links is no longer useful.*

requirement to achieve a Carrier-to-Interference (C/I) ratio of about 18 dB. This requires that a channel used in one cell is not reused in a nearby cell. In CDMA, the wideband channel is reused in every cell.

In CDMA, frequency reuse efficiency is determined by the signal-to-interference ratio that results from all the system users within range, instead of the users in any given cell. Since the total capacity becomes quite large, the statistics of all the users are more important than those of a single user. The "law of large numbers" can be said to apply. This means that the net interference to any given signal is the average of all the users' received power times the number of users. As long as the ratio of received signal power to the average noise power density is greater than a threshold value, the channel will provide an acceptable signal quality. With TDMA and FDMA, interference is governed by a "law of small numbers" in which "worst-case" situations determine the percentage of time in which the desired signal quality will not be achieved.

The primary parameters that determine CDMA digital cellular system capacity are processing gain, E_b/N_0 (with the required margin for fading), voice duty cycle, frequency reuse efficiency, and the number of sectors in the cell site antenna. Additionally, for a given blocking probability, the larger number of voice circuits provided by CDMA results in a significant increase in trunking efficiency, which serves a larger number of subscribers per voice circuit.

For example, if a spread spectrum bandwidth of 1.25 MHz is utilized by mobile stations transmitting continuously at 9600 bps and if the modulation and coding technique utilized requires an E_b/N_0 of 6 dB, then up to 32 mobile stations could transmit simultaneously, as long as they are each power-controlled to provide equal received power at the receiving location. In a CDMA cellular system, this capacity is reduced by interference received from neighboring cells and increased by other factors, as discussed in Section 4.

3.8 Voice Activity Detection

In a typical full duplex two-way voice conversation, the duty cycle of each voice is less than 35%. It is difficult to exploit the voice activity factor in either FDMA or TDMA systems because of the time delay associated with reassigning the channel resource during the speech pauses. With CDMA, it is possible to reduce the transmission rate when there is no speech, and thereby substantially reduce interference to other users. Since the level of other user interference directly determines capacity, the capacity is increased by approximately a factor of two. This also reduces average mobile station transmit power requirements by approximately a factor of two.

3.9 Frequency Reuse and Sectorization

In CDMA, the wideband channel is reused in every cell. The total interference at the cell site to a given inbound mobile station signal is comprised of interference from other mobile stations in the same cell plus interference from mobile stations in neighboring cells. In other words, each mobile station's signal competes with all the other mobile station signals. The contribution of all the neighbor cells is equal to approximately half the interference due to the mobile stations within the same cell. The frequency reuse efficiency of omni-directional cells is shown in Section 4 to be the ratio of interference from mobile stations within a cell to the total interference from all cells, or about 65%. Figure 3-4 shows the percentage of interference contributions from neighboring cells. Each cell in the first tier contributes about 6% of the total interference so the entire first tier contributes an average of 6 times 6% or 36%; cells in the second and greater tiers contribute less than 4%.

When directional cell site antennas are used (e.g., typical 120° sector antennas) the interference is simply divided by three because, on the average, each antenna receives only in the direction of one-third of the mobile stations. The capacity supportable by the total system is therefore increased by nearly a factor of three.[2]

[2] 2.55 actually due to adjacent antenna overlap.

CCIR FACT SHEET

Study Group: US 8D	Date: Nov. 13, 1992
Doc. No.: USSG 8D-20 (Rev. 2)	Ref: Question 84-1/8 (Dec. 8/41(Rev.2)

Document Title: MULTI-LAYER INTERFERENCE ANALYSIS AND SIMULATION PROGRAM

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Purpose/Objective:

To introduce a multi-layer interference analysis and simulation program for the development of technical parameters and criteria for frequency sharing between LEO and GSO satellite systems and among multiple LEO RDSS/MSS Satellite Systems operating in the 1-3 GHz band. Use of such a program will assist in developing criteria to enhance sharing and to identify system design and operational factors which can improve the sharing situation.

Abstract:

Due to the technical and operational characteristics of LEO satellite systems, the interference situation between GSO and LEO satellite systems cannot be evaluated fully using conventional techniques of interference analysis. To gain understanding of the multi-layer interference situation and to develop sharing criteria, a multi-layer interference analysis and simulation program was developed. This analysis and simulation program covers interference among five (5) layers of interaction:

Layer 1: Geometry (orbital dynamics, constellations, etc.)
Layer 2: Antenna beams, patterns and mutual coupling
Layer 3: Frequency assignment (beam, channel, time etc.)
Layer 4: Channel characteristics and link (power, waveform, MA, etc.)
Layer 5: Traffic/user distribution

Several cases of interference are analyzed and discussed in this paper.

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INFORMATION PAPER
MULTI-LAYER INTERFERENCE ANALYSIS AND SIMULATION PROGRAM

I. Introduction

WARC-92, in adopting Interim Procedures for the Coordination and Notification of Frequency Assignments of Non-Geostationary-Satellite Networks in Certain Space Services, Resolution COM5/8 (now Resolution 46), invited the CCIR "to study and develop Recommendations on the coordination methods, the necessary orbital data relating to non-geostationary-satellite systems, and the sharing criteria" that would be used to facilitate coordination. This paper discusses the development and use of a multi-layer interference analysis and simulation program which has been developed to evaluate interference between non-geostationary and geostationary satellites and between multiple non-geostationary satellites. In developing this program, the key parameters of the systems required for such an analysis have been identified. The methodology of the program is discussed along with certain sample results. In addition to evaluating interference, this type of analysis can be used to assist in the development of sharing criteria needed to effect coordination of non-geostationary systems.

Since the relative position and pointing of the GSO and LEO satellites constantly change, the parameters affecting interference, both between GSO and LEO satellites, and between LEO satellites, also will change with time and satellite positioning. With these changing parameters, the interference situation cannot be evaluated fully using conventional techniques of interference analysis. To gain understanding of the interference situation and to develop sharing criteria, a multi-layer interference analysis and simulation program was developed. This analysis and simulation program analyzes and simulates interference situation among five (5) layers of interaction:

- Layer 1: Geometric interaction
- Layer 2: Antennas interaction
- Layer 3: Channel Assignment interaction
- Layer 4: Channel Characteristics interaction
- Layer 5: Traffic /user distribution

This information paper introduces one of the simulation techniques to analyze the interference situation among various MSS Satellite Systems. Some sample simulation results are also given in this paper as examples.

A key objective of an analysis and simulation program is to develop a mechanism to establish the power spectral density of interference. Once this PSD is established, individual MSS systems should be able to use it to estimate the aggregate Io and the impact on its own EB/(No+Io). This aggregate PSD can also be used as a measure to allocate expected interference noise from different MSS systems, and thus can be used to develop criteria to be facilitate frequency sharing among different MSS systems.

2. The Five Layer Model of Interference

A systematic approach to partition the complex interference situation among multiple MSS Satellite Systems (both GSO and non-GSO) is to develop a multi-layer interference model such that computer analysis and simulation program can be developed around each layer. Initially, five major layers of the interference situation have been identified and computer simulation programs have been developed around these five layers.

2.1 Layer 1: Geometric Layer

Since the relative position and pointing of GSO and LEO satellites constantly change, it is necessary to develop some common reference systems for all satellite systems such that all satellites and user terminals can have a specific coordinate with respect to the same reference point. In this layer, the center of the earth has been identified as the center of this reference system. Each interference source (i.e., a transmitter) and victim (i.e., a receiver) is identified by its own coordinate with respect to the center of the Earth. The Z-axis of any point is defined as the vector from this particular point to the center of the earth. The X-axis is defined as the same of the velocity vector of this point. Figure 1 illustrates this geometric layer and the reference system.

The main purpose of this geometric layer is to determine whether any pair of interference source and interference victim has the line-of-sight relation. It is assumed in this simulation program that there is interference when a source and a victim are in direct line-of-sight. Scattering reflection and refraction effects are considered secondary effects and are not included in the program at this stage. These secondary effects can be incorporated into the program if models of these effects be developed.

Major parameters to be input into this geometric layer include:

- satellite altitude
- inclination angle
- orbit phasing
- orbit location or sub-satellite point (for GSO)
- orbit eccentricity
- apogee and perigee
- others

The computer program would simulate orbits and constellations of different GSO or non-GSO systems, calculate the relative positions of each points (either an interference source or victim) and determine whether two points (i.e. source and victim) are in line-of-sight or being blocked by earth, at any time of the simulation period.

2.2 Layer 2: Antenna Layer

Once the line-of-sight between the interference source and interference victim is established, the interaction between the source antenna and the victim antenna has to be modeled. Figure 2 illustrates the interaction among a single interference source and multiple interference victims.

An interference source can transmit interference through the mainbeam, sidebeams or backlobes of its transmit antenna and an interference victim can receive interference through the mainbeam, sidelobes or backlobes of its receive antenna.

To analyze the interference situation, the actual measured antenna patterns, including both main beam and sidelobes, or computer simulated patterns can be located at any point of the coordinate to simulate the transmit or receive antenna. The relative distance and spatial loss between the source and victim can be calculated by Layer 1 programs. Thus the relative gain between the source and victim along the line-of-sight direction can be determined.

Another factor affecting the relative gain between the source and the victim is the polarization isolation between the source and the victim. The computer program examines the orientation of the source and victim antennas, the relative polarization isolation and the resulting relative gain between the source and the victim.

The analysis may have to be augmented to consider cases where antenna directivity is independent of satellite pointing.

2.3 Layer 3: Channel Assignment

After the relative gain(s) between the interference source and the interference victim(s) have been established by the computer programs in Layer 2, Layer 3 represents the time, frequency and beam assignments at each points. Figure 3 shows an example of the Channel Assignments (time, frequency and beam) of a sample point (either a source or a victim).

Different MSS systems have their own unique frequency plan, channelization plan, frequency re-use plan and beam hopping plan. All these have been modeled and incorporated into Layer 3 programs.

2.4 Layer 4: Channel Characteristics

Layer 4 is in fact a sub-layer of Layer 3, which describes the detailed characteristics of the channel modeled in Layer 3. These channel characteristics include:

- modulation wave form e.g. $(\text{Sin } X/X)^2$ or others
- signal filtering
- power or power spectral density (PSD)
- frame structure (for FDMA/TDMA)
- spectral spreading (for FDMA/CDMA)

As an example, Figure 4 illustrates the channel characteristics of three different approaches (FDMA, FDMA/TDMA and FDMA/CDMA).

2.5 Layer 5: Traffic and User Distribution

The traffic distribution of a MSS satellite is highly local time dependent. During the busiest hours (e.g., 9 to 11 a.m. or 5 to 7 p.m.) the satellite could be fully loaded. In the late evening or early morning, the satellite could be only used lightly. Figure 5a is a typical traffic distribution over a 24-hour period of local time. The traffic distribution of each satellite affects the interference generated by this satellite at a specific time of the day. For simplicity, similar traffic distribution profiles are used for MSS satellites. The total number of channels carried by each MSS satellite can be adjusted as an input to the program of this Layer.

Modeling of the user distribution is much more difficult. Non-uniform distribution of users is the more likely case. However, to simplify this problem, models of user distribution are identified: Uniform Distribution Model and Non-overlapped

Distribution. In the future, additional modeling should be considered to address non-uniform distribution.

In the uniform distribution model, it is assumed that users of different MSS systems are distributed evenly and uniformly over the same geographic area (Figure 5b). In the non-overlapped distribution, it is assumed that users of different MSS systems are located in different geographic areas (Figure 5c).

Combining the traffic distribution profile of a MSS satellite and the user distribution, interference between users and satellites, and between satellite and satellite can be simulated for a long period of time. However, to reduce the complexity of the problem, user-to-user interference is not considered in this Layer.

3. <u>Assumptions and Outputs</u>

Many assumptions were made to reduce the complexity of the simulation, for example:

- If actual antenna pattern is not available, equivalent, simulated antenna gain pattern is used for certain antenna apertures.

- It is assumed that an FDMA/ TDMA MSS systems is fully synchronized within itself and a simple time-average factor can be used to estimate the interference generated by the burst type of transmission.

- It is assumed that there is no correlation and synchronization between different MSS systems, whether they are FDMA/TDMA, FDMA or FDMA/CDMA.

- The power spectral density (PSD) is "measured" at the output port of the receiving antenna of the victim.

- Voice activation and "keep alive" circuits are not included in the analysis.

The main output of this multi-layer simulation program is the Power Spectral Density (PSD) generated by various sources of interference at any given victim location and at any time of the day. To visualize this output, one can imagine that a spectrum analyzer is used at a specific victim location to estimate the interference power spectral density over a certain period of time. Sweeping the spectrum analyzer over a large band provides an overall estimate of the interference situation and sweeping over a finely quantitized band provides a more accurate estimate of the interference power.

To make the program output more comprehensive, several data reduction programs and statistic programs were developed to analyze the outputs. Figure 6 is an example of a typical output of this simulation program and Figure 7 is the statistical summary of a specific interference situation. Figure 6 shows the spectral power density at two frequencies, of the sum of all interference from various sources, over a three hour orbit at a specific LEO satellite. Figure 7 provides the statistical summary of Figure 6, which shows over 65% of time, the psd of interference at this specific point of the constellation, the interference level would be over -227 dBw/4 kHz. Figure 6 and Figure 7 only provide a simulation for three hour orbit time. If longer orbit time is simulated, then more realistic estimation of the interference interaction can be studied.

4. Conclusion

This analysis and simulation program is an important first step to the development of a tool which can be used to measure interference of MSS systems, including GSO and LEO satellites, ultimately leading to the identification of sharing criteria and system design parameters which can promote spectrum sharing.

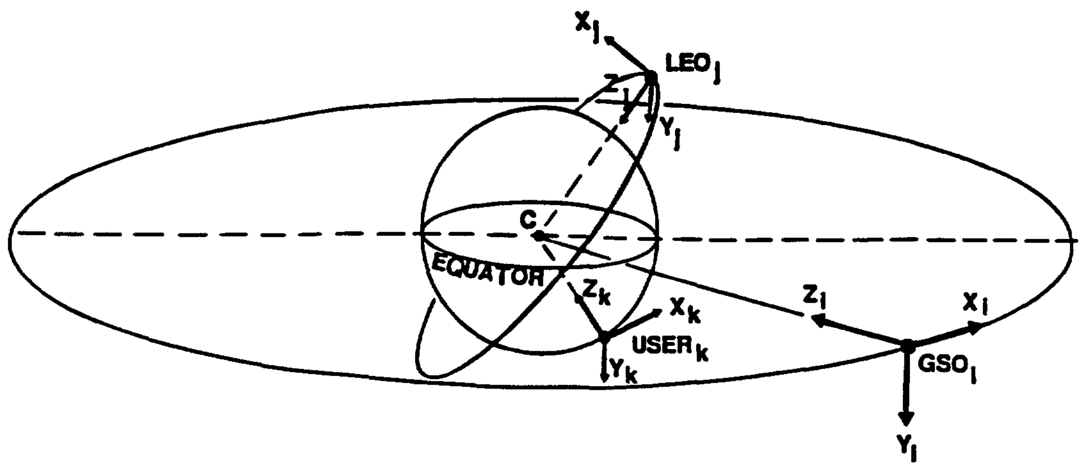

Figure 1 - Co-ordinate System of the Geometric Layer

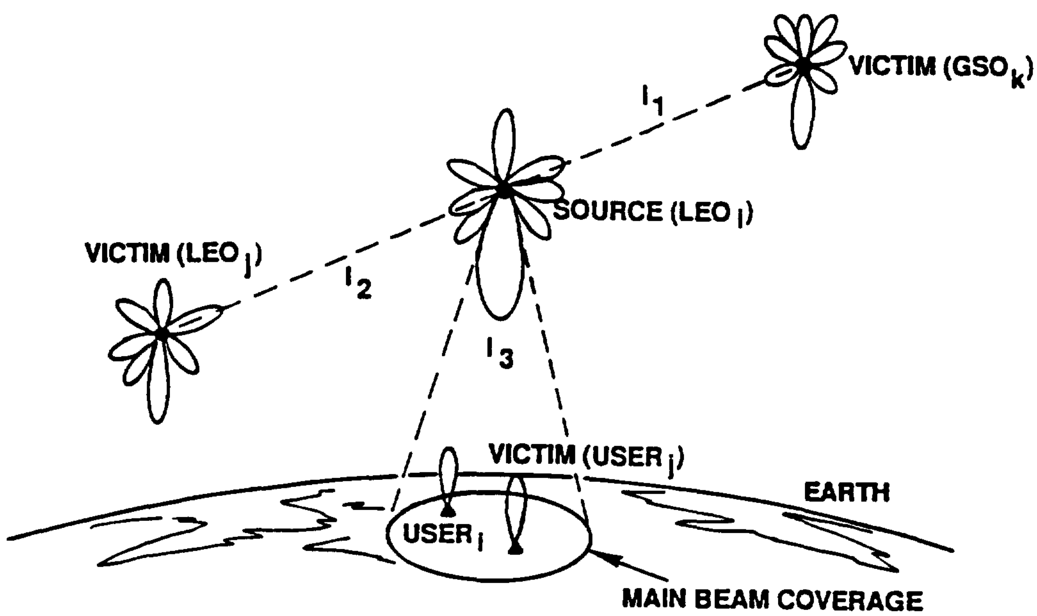

Figure 2 - Example of Antenna Interaction

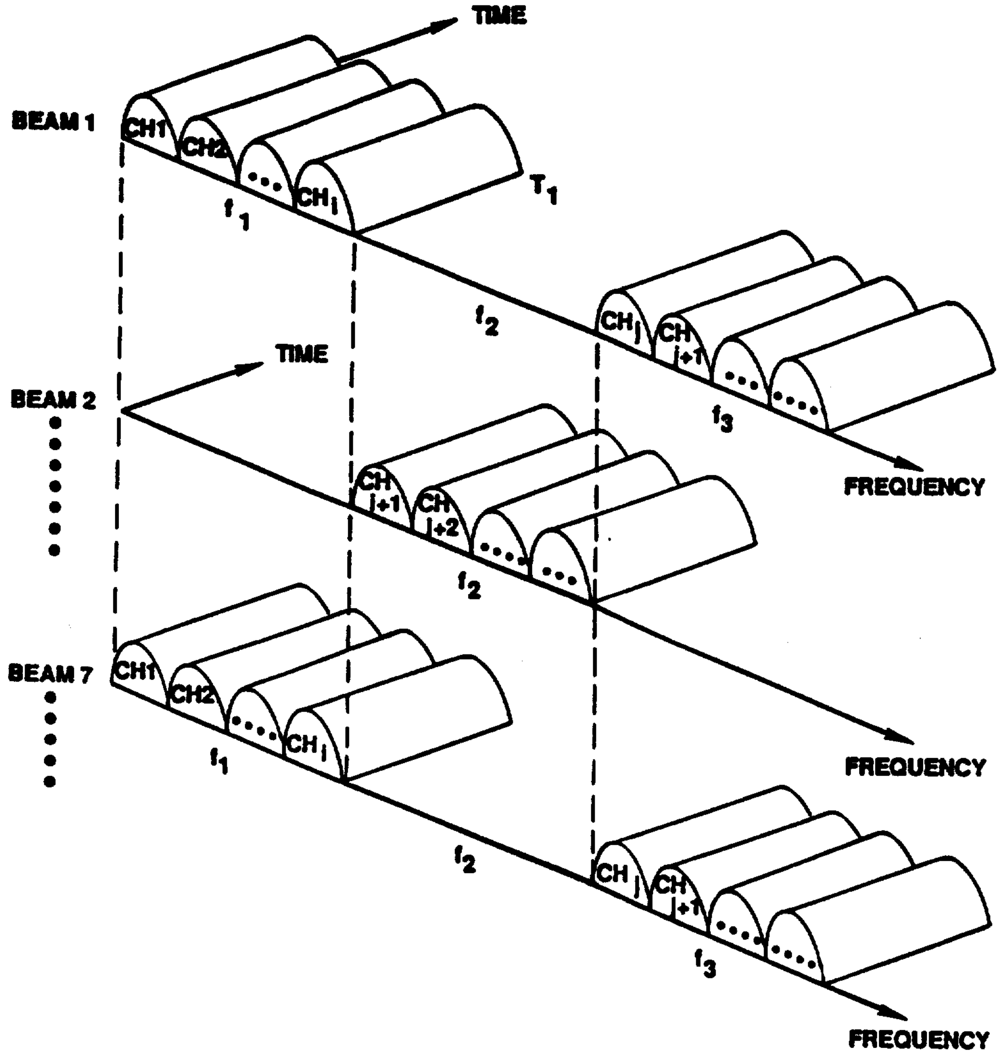

Figure 3 - Channel Assignments

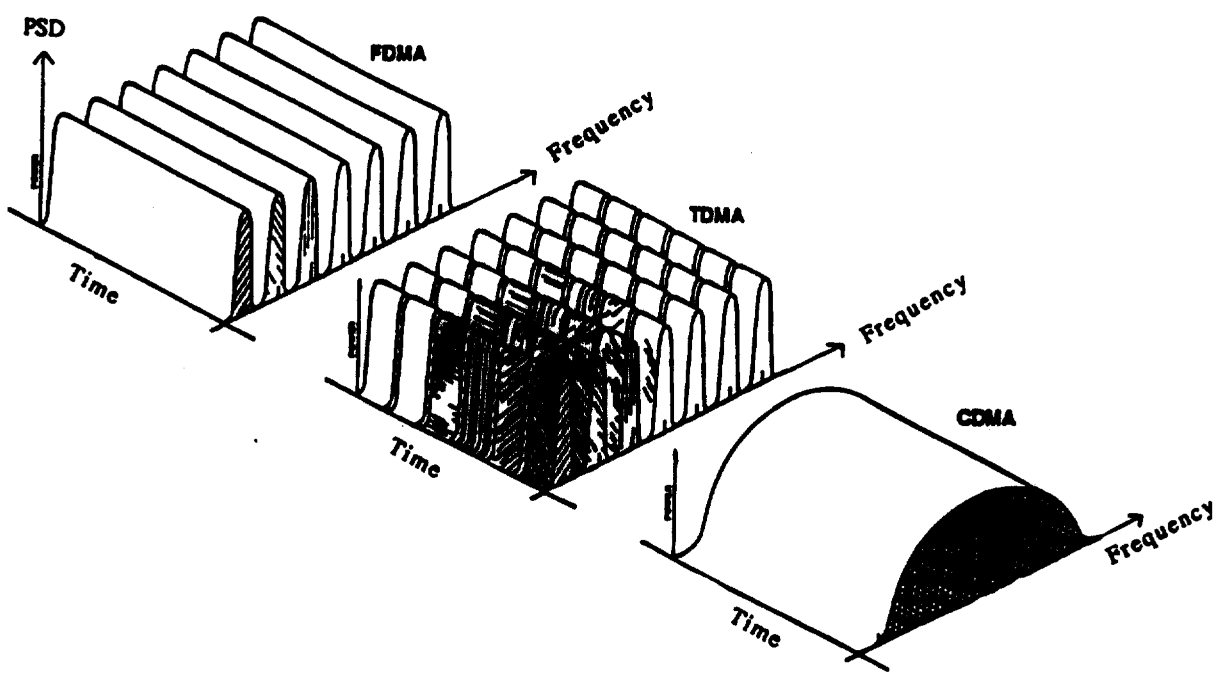

Figure 4 - Channel Characteristics

Figure 4 - Channel Characteristics